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Some Bacteriological and Chemical Effects of Calcium and Magnesium Limestones on Certain Acid Iowa Soils

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SUMMARY AND CONCLUSIONS

An investigation was made of the comparative effects of calcium and magnesium limestones applied to Carrington loam, Tama silt loam and Grundy silt loam. These soils are all acid in reaction and have a lime requirement of about 3 tons per acre. They occur extensively in Iowa and are among the better agricultural soils of the state.

Studies were made of the effects of the limestones on the hydrogen-ion concentration, the lime requirement, the exchangeable hydrogen, calcium and magnesium and on the degree of saturation of the exchange complex with bases. Studies were also made of the nitrate content and the nitrifying power of these soils as influenced by the two limestones, and of the yields of wheat and red clover on the Carrington loam and the Tama silt loam treated with the two limestones.

The data obtained indicate that the calcium limestone reacted somewhat more rapidly with the soil acids than the magnesium limestone. It reduced the acidity more and stimulated a greater production of nitrates in the soil during the first few weeks after the limestones were applied. This advantage of the calcium limestone was apparently overcome by the magnesium limestone rather quickly and after 8 to 12 weeks there was no apparent difference in the effects of the two limestones on any of the chemical or bacteriological characteristics of the soils studied. Neither limestone was superior in its effects on the yields of wheat and clover.

It is concluded from these experiments that in agricultural practice either limestone may be used to advantage to correct the acidity of soils, their long-time effects being practically identical.

Some Bacteriological and Chemical Effects of Calcium and Magnesium Limestones on Certain Acid Iowa Soils[1]

By Harold L. Dean and R. H. Walker[2]

The comparative value of calcium and magnesium limestones has been a problem of considerable interest to agronomists for many years. It was first suggested in the early experimental work conducted about 1900, mainly by Loew, on the functions of calcium and magnesium in plant nutrition and growth. As a result, this hypothesis was formulated: Calcium and magnesium are toxic to plants when either element occurs in excess of a definite ratio. The announcement of this hypothesis greatly stimulated research on the problem, but although some of these investigations yielded data supporting the hypothesis many more did not. Several factors affect the relative values of the two limestones, and the type of soil to which the limestones are applied is undoubtedly the most important. It is obvious, for example, that soils deficient in magnesium may be benefited to a greater extent by a magnesium limestone than by a calcium limestone. Other factors influencing the comparative value of the two limestones are the purity and the degree of fineness of the limestones themselves. These are secondary, however, and can be controlled in comparative experiments.

Although experiments with calcium and magnesium limestones have been conducted elsewhere and on different types of soil, there is only limited information concerning the comparative effects of these limestones on Iowa soils. Walker, Brown and Young[3] studied the comparative effects of these materials on Grundy silt loam. They found that the calcium limestone was somewhat more effective than the magnesium limestone in reducing the hydrogen-ion concentration. The differences, however, were not large, and after the sixth week they were probably of little significance. From the practical standpoint, it was concluded that there was no significant difference in the effects of the two limestones on the hydrogen-ion concentration of the Grundy silt loam.

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[1] Project 227 of the Iowa Agricultural Experiment Station.

[2] The authors are greatly indebted to Dr. P. E. Brown for the suggestions and criticisms offered during the progress of this work.

[3] Ia. Agr. Exp. Sta., Res. Bul. 148. 1932.

The experiments reported in this bulletin were designed to extend this work and to determine the comparative effects of calcium and magnesium limestones on the bacteriological and chemical conditions of other Iowa soils, and also to study the effects of these materials on the crop yields under controlled conditions in the greenhouse.

EXPERIMENTAL

The experimental work consisted of greenhouse and laboratory experiments in which the comparative bacteriological and chemical effects of a high-calcium and a high-magnesium limestone on three important Iowa soils were studied.

SERIES I. A COMPARISON OF CALCIUM AND MAGNESIUM LIMESTONES ON CARRINGTON LOAM AND TAMA SILT LOAM IN GREENHOUSE EXPERIMENTS

The soils used in this experiment were Carrington loam and Tama silt loam.[4] The Carrington loam was obtained from Hardin County. It has a dark brown to black, mellow, friable, surface soil extending to a depth of 12-14 inches. The subsoil is a yellowish-brown silty clay to clay, becoming heavier in texture and lighter in color at lower depths. This soil is acid and normally shows a lime requirement of about 3 tons per acre.

The Tama silt loam was obtained from Marshall County. It is a dark brown, moderately heavy silt loam extending to a depth of 12 to 16 inches. The subsoil is a yellowish-brown, friable, compact silty clay loam. This soil is also acid and has a lime requirement of about 3 tons per acre.

The soils were brought to the greenhouse, screened, thoroughly mixed and placed in 4-gallon glazed stone pots, with 30 pounds of soil per pot. There were 32 pots for each soil type, and these were divided into two series. One series for each soil type was treated with a limestone having a high calcium and a low magnesium content and the other with a limestone having a high magnesium content. The calcium and magnesium carbonate contents of these limestones are shown in table 1. This table also shows the results of the mechanical analysis of the two limestones.

To study the two limestones under comparable conditions regarding fineness of division, the calcium limestone was used without alteration. The magnesium limestone, however, was prepared by mixing different fractions of the magnesium lime-

[4] A more detailed description of these soils is given in Ia. Agr. Exp. Sta. Soil Survey Rpts. 25 and 38.

stone in the proper proportions to give a material of the same composite degree of fineness as the calcium limestone.

The limestones were applied to these soils at the rates of 1½, 3 and 6 tons per acre. Each treatment was made in quadruplicate pots of soil, and untreated pots were left for checks in each case. Each of the soils used had a lime requirement of approximately 3 tons per acre. The limestones were thoroughly mixed with the soil, and the moisture content was then adjusted to near the optimum for the growth of crops. Two pots of soil of each treatment were cropped to wheat and red clover and the other two were fallowed and sampled for laboratory analyses. The red clover seed was inoculated with *Rhizobium trifolii* before sowing, and the soil of one pot in each duplicate series was inoculated with a pure culture of *Azotobacter chroococcum*.

The soils of the fallow series were sampled at the end of 1, 2, 4, 8, 12, 16 and 20 weeks after the limestones were applied. Determinations were made of the moisture content, hydrogen-ion concentration, lime requirement, nitrate-nitrogen content and nitrifying power of the soils at these samplings. Also a study was made of the degree of saturation with bases of the exchange complex of the soils after 3 and 6 months. The latter study included determinations of the exchangeable hydrogen, calcium and magnesium, and of the total base exchange capacity of the soils.

INFLUENCE OF CALCIUM AND MAGNESIUM LIMESTONES ON THE HYDROGEN-ION CONCENTRATION OF CARRINGTON LOAM AND TAMA SILT LOAM

The effects of the various additions of calcium and magnesium limestones on the hydrogen-ion concentration of the soils were determined electrometrically by the quinhydrone method (table 2).

TABLE 1. THE MECHANICAL AND CHEMICAL COMPOSITION OF THE LIMESTONES USED.

	Calcium limestone (percent)	Magnesium limestone (percent)
Coarser than 5-mesh	0.45	4.05
Between 5- and 10-mesh	13.145	15.335
Between 10-and 20-mesh	35.045	10.33
Between 20-and 40-mesh	46.22	21.30
Between 40-and 60-mesh	1.725	17.35
Between 60- and 80-mesh	0.15	5.55
Between 80- and 100-mesh	0.10	8.685
Between 100- and 200-mesh	0.485	7.32
Finer than 200-mesh	2.42	10.09
Calcium carbonate content	93.50	49.20
Magnesium carbonate content	1.65	21.20

The data show that, while there are a few exceptions, in general the calcium limestone decreased the hydrogen-ion concentration of both soils to a greater extent during the first 4 months of the experiment than did the magnesium limestone. This is well illustrated in the Carrington loam, treated with 3 tons of calcium limestone, where the pH was 6.34 4 weeks after the limestone was applied, whereas, the soil treated with a similar amount of magnesium limestone had a pH of 6.18. At the end of the experiment, or by the twentieth week, however, the magnesium limestone had decreased the hydrogen-ion concentration to practically the same value as had the calcium limestone. The Tama silt loam treated with 3 tons of calcium had a pH of 6.16 4 weeks after the applications were made, whereas, the soil treated with the same amount of magnesium limestone had a pH of 5.84. By the twentieth week the Tama soil treated with the magnesium limestone showed a slightly higher pH than that treated with the calcium limestone.

The conclusion is substantiated by a statistical analysis of the data (by the analysis of variance method). The differences

TABLE 2. THE pH OF CARRINGTON LOAM AND TAMA SILT LOAM TREATED WITH VARIOUS AMOUNTS OF CALCIUM AND MAGNESIUM LIMESTONE.

Averages of duplicate pots of limed soil and of quadruplicate pots of untreated soils. Standard error of the mean difference between duplicates, 0.038 pH.

Time in weeks	No lime	Calcium limestone			Magnesium limestone		
		1½ tons	3 tons	6 tons	1½ tons	3 tons	6 tons
			Carrington loam				
0	5.58	5.58	5.58	5.58	5.58	5.58	5.58
1	5.54	5.84	6.02	6.61	5.76	6.00	6.16
2	5.54	5.94	6.16	6.88	5.97	6.21	6.68
4	5.53	6.02	6.34	6.78	5.93	6.18	6.42
8	5.50	6.03	6.28	6.66	5.82	6.14	6.58
12	5.47	6.03	6.48	7.15	5.78	6.18	6.64
16	5.28	5.91	6.20	6.78	5.72	5.84	6.41
20	5.24	5.77	6.08	6.76	5.79	6.14	6.72
			Tama silt loam				
0	5.17	5.16	5.16	5.16	5.19	5.19	5.19
1	5.24	5.56	5.92	6.45	5.42	5.56	5.70
2	5.34	5.63	5.80	6.59	5.78	6.02	6.30
4	5.23	5.70	6.16	6.67	5.55	5.84	6.06
8	5.22	5.79	6.06	6.54	5.66	5.96	5.79
12	5.20	5.83	6.07	6.75	5.64	5.93	5.82
16	5.16	5.54	5.79	6.53	5.52	5.75	6.08
20	5.17	5.66	5.86	6.26	5.58	6.04	6.56

between the effects produced by the two limestones were found to be highly significant. Although these differences are significant, however, their magnitude is not sufficiently large to be of much importance in most agricultural practice—except perhaps where the 6-ton applications were made. It may be concluded, therefore, that in general farm practice, where limestone is given ample time to react with the soil, there probably would be no important difference in the decreasing of the hydrogen-ion concentration by the two limestones, compared under similar conditions.

The statistical analysis revealed further that there was a highly significant increase in the pH effected by increases in amounts of limestone, and also that the increases in the pH effected by the limestones from week to week as they reacted with the soils were highly significant.

INFLUENCE OF CALCIUM AND MAGNESIUM LIMESTONES ON THE LIME REQUIREMENT OF CARRINGTON LOAM AND TAMA SILT LOAM

In this investigation the lime requirements of the soils treated with calcium and magnesium limestones were determined by the Hardy and Lewis[5] titration method and by the qualitative thiocyanate method. Results are given in table 3.

The results are in accord with those of the hydrogen-ion studies in that the calcium limestone decreased the lime requirement of the soil more rapidly than did the magnesium. On the Carrington loam the calcium limestone was more effective in decreasing the lime requirement than was the magnesium limestone during the first 3 months. By the end of the experiment, however, the magnesium limestone had decreased the lime requirement of the soil to the same extent or further than had the calcium limestone. On the Tama silt loam there is some indication that the calcium limestone was slightly more effective in neutralizing soil acidity. This is especially true where larger applications of the limestone were used but the differences were not great.

It may be observed that lime requirements of the soils decreased with an increase in the quantity of limestone applied. On Carrington loam, by the end of the first month, the lime re-

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[5] Jour. Agr. Sci. 19:17-25. 1929.

TABLE 3. THE LIME REQUIREMENT OF CARRINGTON LOAM AND TAMA SILT LOAM TREATED WITH VARIOUS AMOUNTS OF CALCIUM AND MAGNESIUM LIMESTONES AS DETERMINED BY THE HARDY AND LEWIS METHOD.

Results expressed in tons of limestone per acre. Averages of duplicate pots of limed soil and of quadruplicate pots of untreated soils.

Time in weeks	No lime	Calcium limestone			Magnesium limestone		
		1½ tons	3 tons	6 tons	1½ tons	3 tons	6 tons
Carrington loam							
4	2.75	2.10	1.64	1.26	2.44	2.21	1.69
8	2.70	2.09	1.44	0.84	2.44	2.09	1.65
12	2.53	2.16	1.80	1.03	2.06	1.78	1.30
16	2.54	2.27	1.70	0.96	1.98	1.76	1.41
20	2.63	2.23	2.04	1.44	2.12	1.46	1.02
Tama silt loam							
4	3.03	2.66	2.50	1.68	2.42	2.68	2.20
8	3.39	2.84	2.51	1.82	3.16	2.64	2.20
12	3.31	2.78	2.32	1.48	2.82	2.56	1.85
16	3.10	2.86	2.05	1.41	2.52	2.01	1.69
20	3.01	2.08	1.66	0.84	2.89	2.51	1.72

quirement had been decreased from 2.75 tons per acre in the untreated soil to 1.64 tons per acre in the soil treated with 3 tons of calcium limestone and to 1.26 when twice that amount was applied. At the end of the experiment similar differences were observed. In the soils treated with magnesium limestone the decrease in lime requirement of the soil was also related to the amount of limestone that had been applied. The lime requirement of the untreated Tama silt loam was somewhat higher than that of the untreated Carrington loam, but the two limestones apparently acted similarly on the two soils.

The qualitative thiocyanate method for determining the lime requirement gave results which were quite similar to those obtained with the Hardy and Lewis titration method. On Carrington loam the results indicated very little difference between the limestones applied in small quantities. There was, however, a noticeable difference in the results induced by the different materials applied at the rate of 3 and 6 tons per acre. On Tama silt loam little or no difference in the lime requirement was obtained through the use of calcium and magnesium limestones as determined by the qualitative method.

INFLUENCE OF CALCIUM AND MAGNESIUM LIMESTONES ON THE BASE EXCHANGE COMPLEX OF CARRINGTON LOAM AND TAMA SILT LOAM

To determine the effects of various additions of calcium and magnesium limestones on the total exchangeable bases, exchangeable hydrogen, exchangeable calcium, exchangeable magnesium and degree of saturation, the soils were sampled at intervals of 3 and 6 months, and analyzed for the various constituents. The barium acetate-ammonium chloride leaching method[6] was employed in the base exchange studies, except when the exchangeable calcium and magnesium were determined. In the latter case the ammonium acetate leaching method and also the analytical methods for calcium and magnesium of Schollenberger and Dreibelbis[7] were employed. The results are presented in table 4.

BASE EXCHANGE CAPACITY

According to the generally accepted theories of the base exchange complex, the base exchange capacity of a soil is a rather definite or fixed characteristic. There was, however, some variation in the results obtained in the base exchange capacity determinations on the variously treated Carrington and Tama soils. The variations were not large and they were not systematic. It was assumed, therefore, that they were chiefly the result of the difficulties inherent in the methods for making the determinations, rather than the result of the limestone treatments. For these reasons average values for all the determinations on each soil type were used as a working basis in subsequent calculations of the amount of exchangeable bases and the degree of saturation of the base exchange complex with bases. The mean base exchange capacity of the Carrington loam was 17.61 m.e. with a standard error of 0.41 m.e., and for the Tama silt loam it was 22.81 m.e. with a standard error of 0.27 m.e.

EXCHANGEABLE HYDROGEN

In order to compare the effects of the calcium and magnesium limestone treatments, measurements were made of the amount of exchangeable hydrogen remaining in the base exchange complex after the limestones had reacted 3 and 6 months respectively. The determinations were made simultaneously with the other base exchange analyses. From the data of table 4 it is apparent that in the samples of Carrington loam there was a decrease in the amount of exchangeable hydrogen in the exchange complex of the lime-treated soils after 3 months. The calcium limestone tended to be slightly more effective in decreasing the exchangeable hydrogen during the

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[6] Ia. Agr. Exp. Sta. Res. Bul. 148, 1932.
[7] Soil Science 30:161-173. 1930.

TABLE 4. THE BASE EXCHANGE CONTENT AND THE DEGREE OF SATURATION OF CARRINGTON LOAM AND TAMA SILT LOAM TREATED WITH DIFFERENT AMOUNTS OF LIMESTONE.

Amount of limestone applied	Calcium limestone					Magnesium limestone				
	M.E. exchangeable bases				Percent satur-ation	M.E. exchangeable bases				Percent satur-ation
	Hydrogen	Calcium	Magne-sium	Total bases		Hydrogen	Calcium	Magne-sium	Total bases	
	Carrington Loam									
	3 months					3 months				
No Lime	9.35	11.01	2.69	8.26	46.90	9.03	10.96	3.16	8.58	48.72
1½ tons	7.63	13.10	2.66	9.93	56.67	7.95	11.61	3.65	9.66	54.86
3 tons	6.18	14.70	2.68	11.43	64.91	6.68	12.16	4.14	10.93	62.07
6 tons	4.05	17.93	2.76	13.56	77.00	5.00	13.30	4.94	12.61	71.61
	6 months					6 months				
No Lime	10.10	12.38	2.26	7.51	42.65	9.48	11.79	3.35	8.13	41.17
1½ tons	8.55	14.52	2.54	9.06	51.45	7.68	12.30	3.89	9.93	56.39
3 tons	7.81	18.50	2.48	9.80	55.65	6.03	13.42	4.73	11.58	65.76
6 tons	6.88	22.42	2.80	10.73	60.93	5.25	14.87	5.93	12.32	69.96
	Tama Silt Loam									
	3 months					3 months				
No Lime	12.65	13.54	3.40	10.16	44.54	11.73	13.22	3.03	11.08	48.58
1½ tons	10.85	16.46	3.38	11.96	52.43	10.73	13.76	3.72	12.08	52.96
3 tons	10.23	18.00	3.46	12.58	55.15	9.93	14.50	3.90	12.88	56.47
6 tons	6.95	22.01	3.13	15.86	69.53	8.33	15.86	5.92	14.48	63.48
	6 months					6 months				
No Lime	14.35	13.99	4.06	8.46	37.09	10.97	13.85	3.80	11.84	51.91
1½ tons	11.53	15.67	3.92	11.28	49.45	9.83	14.92	4.78	12.98	56.90
3 tons	6.93	15.68	3.46	15.88	69.61	7.75	15.79	5.78	15.06	66.02
6 tons	4.48	19.24	3.33	18.33	80.35	5.80	17.24	6.99	17.01	74.57

first 3-months period than the magnesium limestone, the effectiveness being more pronounced with the heavier applications. By the sixth month the magnesium limestone had reduced the amount of exchangeable hydrogen in the soil as much or more than the calcium limestone, the reduction being from 9.48 m.e. per 100 grams of untreated soil to 6.03 m.e. per 100 grams of soil treated with 3 tons of magnesium limestone. The soil treated with 3 tons of calcium limestone had a somewhat larger quantity of exchangeable hydrogen than the soil treated with the magnesium limestone.

It may be concluded from these results that the calcium limestone was apparently more effective in decreasing the exchangeable hydrogen during the first 3 months after application than the magnesium limestone, and that the magnesium limestone was at least equally as effective as the calcium limestone by the sixth month.

On Tama silt loam the limestone treatments also decreased the exchangeable hydrogen of the soil. There was some indication that the calcium limestone was slightly more effective than the magnesium limestone on this soil but the differences are not sufficient to warrant a definite conclusion.

In the calcium limestone treated Carrington loam the base exchange complex increased slightly in content of exchangeable hydrogen from the third to the sixth-month period. In the magnesium limestone treated Carrington loam, however, the exchange complex contained approximately the same quantity of exchangeable hydrogen from one period to the other. In the Tama silt loam there was a tendency toward a reduction of the exchangeable hydrogen in most of the differently treated soils between the third and sixth months.

EXCHANGEABLE CALCIUM

The exchangeable calcium content of Carrington loam and also of Tama silt loam was increased with various lime treatments, the increase being determined by the amount of limestone applied and also by the chemical composition of the limestone. At the end of the first 3 months the calcium limestone considerably increased the quantity of exchangeable calcium in the base exchange complex of these soils. The larger the quantity of limestone applied the greater the quantity of exchangeable calcium found in the exchange complex. The magnesium limestone, which contained only 49.2 percent calcium carbonate, also increased the exchangeable calcium in the base exchange complex, the increase being a function of the amount applied. The increases, however, were much smaller than those obtained with the calcium limestone. Similar results were obtained with the samples taken 6 months after the limestone was applied, except that there was a tendency in most cases toward an increase in the amount of exchangeable calcium present in the base exchange complex with the treated and untreated soils.

It may be concluded from these data that the calcium limestone increased the amount of exchangeable calcium in the soil to a much larger degree than the magnesium limestone.

EXCHANGEABLE MAGNESIUM

The calcium limestone had very little effect upon the exchangeable magnesium content of the Carrington loam and the Tama silt loam during the first 3 months. During the same period the magnesium limestone increased the exchangeable magnesium content of the base exchange complex, the increase being roughly proportional to the amount of limestone added. These results were expected since the calcium limestone contained only 1.65 percent of magnesium carbonate, whereas the magnesium limestone contained 21.2 percent. At the end of 6 months, the soils treated with calcium limestone contained approximately the same amount of exchangeable magnesium that they did at 3 months. The soils treated with magnesium limestone, however, showed an appreciable increase in exchangeable magnesium from the third to the sixth month. The increase was larger where the heavier applications of limestone had been made.

EXCHANGEABLE BASES AND THE DEGREE OF SATURATION

The exchangeable base content of the soils studied was calculated by subtracting the amount of exchangeable hydrogen from the total base exchange capacity of the soils. It is obvious, therefore, that the amount of exchangeable bases in these soils increased with the various treatments of limestone in proportion to the decreases in exchangeable hydrogen, as were previously discussed.

The base exchange complex of the untreated Carrington loam was 46.90 and 48.72 percent saturated with bases in the duplicate series, 3 months after the experiment was set up. These values were increased to 64.91 and 62.07 percent by the application at the rate of 3 tons per acre of the calcium and magnesium limestones respectively. The calcium limestone seemed slightly more effective in increasing the degree of saturation of this soil with bases during the first 3 months than was the magnesium limestone.

The results obtained with the samples taken 6 months after treatment indicate that the magnesium limestone was slightly more effective than the calcium limestone in increasing the degree of saturation of the Carrington loam with bases. These results are in accord with those found in studying the hydrogen-ion concentration of the soil.

With Tama silt loam there was an increase in the degree of saturation of the exchange complex with the various treatments of lime. The calcium and magnesium limestones, 3 months after treatment, gave similar results where the lighter applications were employed. The calcium limestone, however, was more effective in increasing the saturation of the base exchange complex where the limestones were applied at the rate of 6 tons per acre. The calcium limestone, 6 months after application, was again slightly more effective in increasing the degree of saturation of the base exchange complex.

It may be observed that the quantity of total exchangeable bases calculated for either soil and with all treatments was less than the total calcium and magnesium determined in the exchangeable form by the methods employed. Undoubtedly a portion of the soluble calcium and magnesium in the soil was leached from the soil along with the exchangeable ions, and was determined along with the latter. Hence there is indicated a larger quantity of exchangeable calcium and magnesium ions than was actually present in the exchange complex. This emphasizes the need of better methods for base exchange studies in order that a more accurate picture of the base exchange complex and its reactions may be obtained. It is suggested that possibly the soil may be washed free of soluble ions before replacement of the exchangeable ions by the use of some nonelectrolyte solution. It is also felt that an improvement in the methods for determining exchangeable hydrogen would be desirable.

THE INFLUENCE OF CALCIUM AND MAGNESIUM LIMESTONES ON THE NITRATE CONTENT OF CARRINGTON LOAM AND TAMA SILT LOAM

The data given in table 5 show the nitrate content of Carrington loam and Tama silt loam.

Although the nitrate content of these soils increased somewhat as a result of the various limestone treatments and also during the period of the experiment, it did not appear to be

TABLE 5. THE NITRATE CONTENT OF CARRINGTON LOAM AND TAMA SILT LOAM TREATED WITH VARIOUS AMOUNTS OF CALCIUM AND MAGNESIUM LIMESTONES.

Averages of duplicate pots of limed soil and of quadruplicate pots of untreated soils. Results expressed in parts per million.

Time in weeks	No lime	Calcium limestone			Magnesium limestone		
		1½ tons	3 tons	6 tons	1½ tons	3 tons	6 tons
Carrington loam							
4	10	12	12	14	10	10	11
8	16	20	19	21	28	28	59
12	21	21	27	24	26	21	23
16	34	48	46	51	35	36	32
20	35	41	41	56	48	39	44
Tama silt loam							
4	43	35	56	32	39	36	36
8	56	54	43	60	56	60	71
12	72	56	50	56	104	68	76
16	77	74	86	93	86	79	96
20	85	72	75	55	74	95	90

definitely influenced by one limestone more than by the other. It is well-known that the nitrate nitrogen content of a soil is a relatively unstable characteristic, for while certain groups of microorganisms are actively engaged in the production of nitrates, others may be equally as active in their assimilation. Both groups of microorganisms may or may not be influenced alike by the application of different kinds or amounts of limestone. The differences in nitrate content of the soils, therefore, may or may not indicate the superiority of either limestone.

THE INFLUENCE OF CALCIUM AND MAGNESIUM LIMESTONES ON THE NITRIFYING POWER OF CARRINGTON LOAM AND TAMA SILT LOAM

The effects of the various additions of calcium and magnesium limestone to the soils on the nitrification of ammonium sulfate are shown in table 6.

In the case of the Carrington soil the data indicate that the quantity of nitrate nitrogen produced from the oxidation of monium sulfate in the soil 4 weeks after sampling was larger here the calcium limestone was added than where magnesium mestone was used. In the untreated soil 76 p.p.m. of nitrate itrogen were produced, while the nitrate content of the soil treated with 3 tons of calcium limestone was increased to 127 p.p.m. With a similar quantity of magnesium carbonate there was a decrease in the nitrate content, the amount present being

TABLE 6. THE NITRIFYING POWER OF CARRINGTON LOAM AND TAMA SILT LOAM TREATED WITH VARIOUS AMOUNTS OF CALCIUM AND MAGNESIUM LIMESTONES.

Averages of duplicate pots of limed soil and of quadruplicate pots of untreated soils. Results expressed in parts per million.

Time in weeks	No lime	Calcium limestone			Magnesium limestone		
		1½ tons	3 tons	6 tons	1½ tons	3 tons	6 tons
Carrington loam							
4	76	115	127	100	50	61	51
8	102	168	203	241	154	181	195
12	97	158	207	235	151	171	212
16	67	120	152	199	110	131	158
Tama silt loam							
4	113	138	170	194	85	67	64
8	121	171	209	244	137	143	155
12	126	163	178	206	130	167	203
16	133	164	174	218	130	154	195

61 p.p.m. In the nitrification test 8 weeks after treatment with 3 tons of magnesium limestone the nitrate content increased to 181 p.p.m., whereas, in the calcium treated soil it increased to 203 p.p.m. It was found that an increase in the amount of limestone applied effected rather noticeable increases in the nitrifying power of the soil. Eight weeks after the beginning of the experiment 102 p.p.m. of nitrate nitrogen were produced in the untreated soil, whereas, 168 p.p.m. were produced where 1½ tons of calcium limestone were applied. The larger applications increased the nitrifying power to a greater extent; the amount of nitrate nitrogen produced in soil treated with 3 tons of calcium limestone being 203 p.p.m., while 241 p.p.m. of nitrate nitrogen were produced where 6 tons of calcium limestone were applied.

In the case of the Tama silt loam the calcium limestone proved more effective in stimulating nitrification than did the magnesium limestone. The amount of nitrate nitrogen produced from ammonium sulfate during the early periods of the experiment was much larger in the calcium limestone treated soils. At the end of the experiment the nitrate content of the magnesium treated soil had increased considerably but was still slightly lower than that of the calcium treated soils. An increase in nitrification occurred with an increase in the application of limestone.

It is concluded from this series of tests that the magnesium limestone was not quite as effective as the calcium limestone in stimulating the nitrifying power of the soil, especially in the early periods of the experiment. It is believed, however, that in practice over a period of time little or no difference would result between the effects of the calcium and magnesium limestones on nitrification.

INFLUENCE OF CALCIUM AND MAGNESIUM LIMESTONES ON THE YIELDS OF WHEAT AND CLOVER ON CARRINGTON LOAM AND TAMA SILT LOAM

To determine the effect of the addition of calcium and magnesium limestones on the yields of wheat and red clover, an experiment was conducted using Carrington loam and Tama silt loam in pots in the greenhouse. The wheat was harvested when ripe and the weight of grain and straw was determined. The red clover was harvested at the blossom stage. It was then dried and the weight of the crop was determined. This experiment was conducted for 2 years.

The results of this experiment are presented in table 7. It is evident from the data obtained with the wheat crop that there was a slight increase in the yield of grain due to the limestone treatments, the tendency being for the yield to increase slightly with an increase in the quantity of limestone applied. Apparently there was little or no difference between the effects of calcium and magnesium limestones on the yield of grain. The statistical significance of the differences was not tested in this case. The yields of straw were not affected consistently by the limestone treatments.

There was a rather decided increase in the yield of clover with the applications of limestone. The total dry weight of hay produced on the treated soils in each case was greater than that obtained on the untreated soils. The yield increased with an increase in the quantity of limestone applied. It may be noted that the yield of clover on the Carrington loam the first year was increased from 23.2 grams per pot on the untreated soil to 29.8 grams on the soil treated with 3 tons of calcium limestone, and to 32.5 grams on the soil treated with 6 tons of calcium limestone. The magnesium limestone treatments gave similar results, the soil treated with 3 tons of limestone yielding 30.2 grams per pot and the soil treated with 6 tons yielding 31.0 grams. The yields of clover on the Carrington loam were slightly less than they were the first year but the same general effects of the limestone treatments were observed.

The Tama silt loam produced higher yields of clover than did the Carrington loam, but the same general effects were induced

TABLE 7. THE YIELDS OF WHEAT AND CLOVER PRODUCED ON CARRINGTON LOAM AND TAMA SILT LOAM TREATED WITH VARIOUS QUANTITIES OF CALCIUM AND MAGNESIUM LIMESTONE. RESULTS EXPRESSED IN GRAMS PER POT.

Amount of limestone applied	High-calcium limestone						High-magnesium limestone					
	1933			1934			1933			1934		
	Wheat			Wheat			Wheat			Wheat		
	Grain	Straw	Clover	Grain	Straw	Clover	Grain	Straw	Clover	Grain	Straw	Clover
Carrington Loam												
No lime	7.90	10.0	23.2	8.72	11.0	19.4	6.72	9.8	24.5	9.30	11.8	21.8
1½ tons	8.20	11.2	28.5	8.96	12.0	25.8	7.22	10.5	27.0	8.98	10.8	24.0
3 tons	8.10	12.4	29.8	8.13	11.0	27.6	7.65	11.5	30.2	9.85	11.1	28.3
6 tons	7.95	11.8	32.5	10.13	11.8	31.2	8.15	11.8	31.0	12.03	12.5	28.1
Tama Silt Loam												
No lime	9.32	11.8	36.2	10.16	17.0	33.6	9.28	11.5	36.8	10.47	17.2	32.2
1½ tons	10.02	12.5	37.5	11.12	17.1	36.2	9.28	13.2	37.8	10.28	16.8	33.8
3 tons	11.20	14.8	39.0	11.71	16.5	39.5	10.42	14.0	38.8	13.11	16.2	36.2
6 tons	11.22	15.5	41.8	12.38	17.2	45.8	10.15	14.8	40.0	10.72	16.8	40.7

by the various limestone treatments on this soil as on the Carrington loam.

DISCUSSION

In general, the results obtained from the experiments in Series I show that calcium limestone was slightly more effective than the magnesium limestone during the early periods of the experiments, and that the magnesium limestone was equally as effective as the calcium limestone at the end of the experiment. On the basis of the data obtained it is believed that in actual practice where the limestones are allowed to react with the soil acids over a period of time the calcium and magnesium limestones will give rather similar results. This general conclusion agrees with the results obtained by other investigators.

It has been found by some investigators that if the supply of magnesium in the soil is extremely large toxic effects may result from the additions of magnesium limestone. Inasmuch as no large difference was obtained in the effects of the two limestones in these experiments it is apparent that the soils studied do not contain too large a supply of magnesium, as additional applications of a large amount of magnesium limestone did not produce deleterious effects. It is also apparent that the supply of magnesium in the soil is sufficient to meet the needs for plant growth. It seems possible, however, that sometime in the future when larger amounts of calcium and magnesium have been leached from the soil, the supply of available magnesium may become too low for the maximum growth of crops and also for the maximum bacterial activity within the soil. Then it would undoubtedly be desirable to use high magnesium limestones for the correction of soil acidity, for in their use the deficiency of available magnesium in the soil would be corrected. Strictly from the standpoint of the correction of soil acidity in actual farm practice, however, it is doubtful that either kind of limestone is superior to the other when compared on an equivalent purity and fineness basis.

SERIES II. A COMPARISON OF CALCIUM AND MAGNESIUM LIMESTONES ON GRUNDY SILT LOAM IN LABORATORY EXPERIMENTS

The soil used in this experiment was Grundy silt loam and it was obtained from Warren County. The surface soil of this type is a very dark grayish-brown silt loam to a depth of 10 to 16 inches. The subsoil is a grayish-brown silty clay loam mottled with iron stains and grading at 20 to 24 inches into a mottled bluish-gray, rusty brown, yellowish-brown and grayish-brown heavy impervious silty clay to clay.[8]

A representative sample of this soil was taken to the laboratory, screened and thoroughly mixed. One hundred grams of it were placed in each of 376 tumblers and mixed with either calcium or magnesium limestone. The limestone treatments were made in triplicate, using 10, 20, 40, and 100-mesh limestone at rates of 1½, 3 and 6 tons per acre. Pure calcium and pure magnesium carbonates were also employed, being applied at the same rates. Tumblers of untreated soils were used as controls.

The calcium and magnesium limestones were the same as were used in the greenhouse experiment of Series I. The material of different degrees of fineness was obtained by sieving the quarry-run limestone. The 10-mesh limestone is that material which passed through the 10-mesh sieve but was held on the 20-mesh sieve. The 20-mesh limestone is that which passed through the 20-mesh sieve but was held on the 40-mesh sieve. The 40-mesh material is that which passed the 40-mesh sieve but was held on the 60-mesh sieve. The 100-mesh limestone is all the material which passed the 100-mesh sieve. The pure carbonates were of Baker's c.p. grade.

To two of the triplicate tumblers of soil, in addition to the limestone that was added, ammonium sulfate was added at the rate of 30 mgm. N. per 100 gm. of soil in order to study the effects of the limestones on nitrification. Four complete sets of the variously treated soils were prepared at the beginning of the experiment. One set was removed from the incubator at the end of each week for 4 weeks and analyzed for nitrate content by the phenoldisulfonic acid method and for hydrogen-ion concentration by the quinhydrone electrometric method.

INFLUENCE OF CALCIUM AND MAGNESIUM LIMESTONES ON THE HYDROGEN-ION CONCENTRATION OF GRUNDY SILT LOAM

The reaction of the soil treated with calcium and magnesium limestones and carbonates was determined at 1-week intervals for 4 weeks. Results of this study are presented in table 8.

In order to aid in the interpretation of these data, those obtained in the analysis of the soils treated with limestones at the 3-ton rate are presented graphically in fig. 1. The more finely

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[8] A more complete description of the Grundy silt loam is given in Ia. Agr. Exp. Sta. Soil Survey Rpt. 62.

TABLE 8. THE pH OF GRUNDY SILT LOAM TREATED WITH CALCIUM AND MAGNESIUM CARBONATES AND WITH LIMESTONES OF DIFFERENT DEGREES OF FINENESS AND IN VARIOUS AMOUNTS.

Time in weeks	No lime	Calcium limestone and carbonate					Magnesium limestone and carbonate				
		10-mesh	20-mesh	40-mesh	100-mesh	Pure $CaCO_3$	10-mesh	20-mesh	40-mesh	100-mesh	Pure $MgCO_3$
					1½ tons per acre						
1	5.34	5,39	5.36	5.55	5.97	6.25	5.36	5.38	5.46	5.85	6.22
2	5.25	5.32	5.49	5.60	6.12	6.26	5.47	5.58	5.48	6.25	6.19
3	5.29	5.33	5.50	5.61	6.18	6.30	5.38	5.50	5.53	5.82	6.25
4	5.25	5.26	5.26	5.56	5.88	5.98	5.21	5.28	5.43	5.77	6.02
					3 tons per acre						
1	5.34	5.61	5.68	6.02	6.79	7.06	5.53	5.61	5.71	6.39	7.01
2	5.25	5.49	5.60	5.82	6.62	6.74	5.59	5.60	5.75	6.29	6.77
3	5.29	5.46	5.63	5.98	6.67	6.84	5.45	5.60	5.69	6.33	6.93
4	5.25	5.30	5.46	5.77	6.56	6.77	5.25	5.38	5.78	6.43	6.66
					6 tons per acre						
1	5.34	5.71	5.81	6.28	7.63	7.84	5.61	5.75	5.98	6.94	7.99
2	5.25	5.52	5.70	6.09	7.41	7.70	5.60	5.61	5.88	6.81	7.75
3	5.29	5.53	5.72	6.22	7.64	7.87	5.53	5.62	5.75	6.91	7.96
4	5.25	5.56	5.68	6.27	7.50	7.63	5.26	5.50	6.17	6.84	7.65

divided limestones applied at this rate and the pure carbonates increased the pH of the soil to a greater extent during the first 2 weeks than did the coarser limestones. Furthermore, the calcium limestones were more effective in this connection than were the magnesium limestones. Also, the difference between

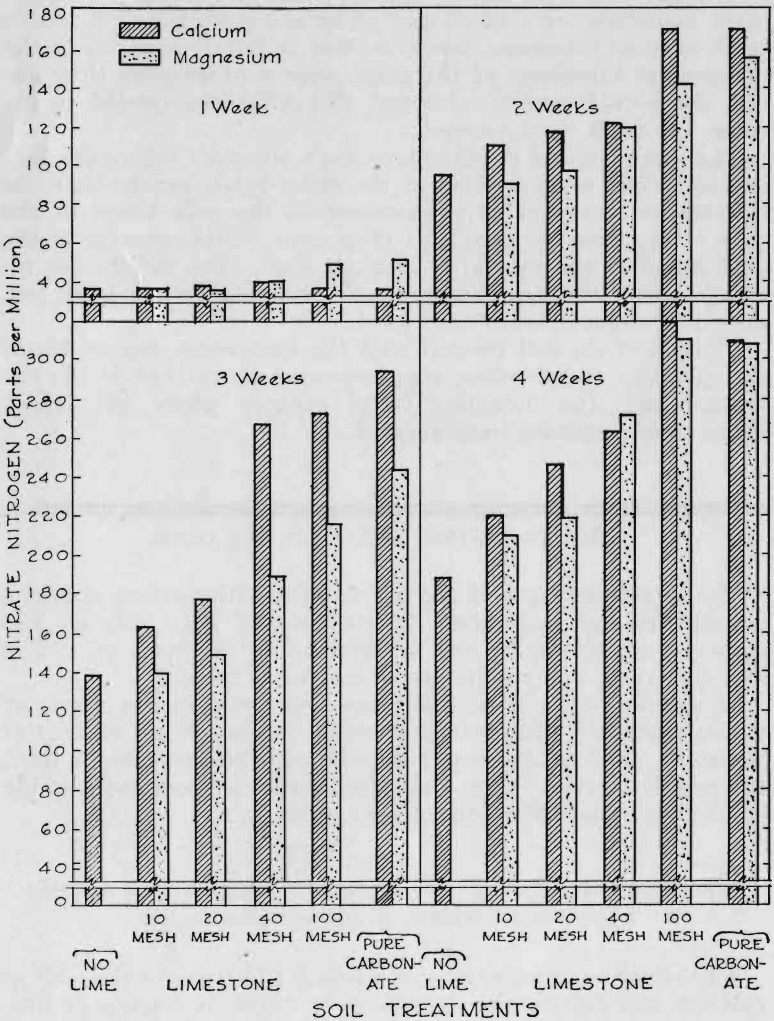

Fig. 1. The pH of Grundy silt loam treated with calcium and magnesium limestones of different degrees of fineness and with pure carbonates at the rate of 3 tons per acre.

the two was more pronounced in the soils treated with the finer materials. The difference in the effects of the two pure carbonates was small.

These same general relationships were evident at the third and fourth week periods with the 3-ton applications, although there were exceptions. In general, differences between the two limestones when applied as the 10, 20, or 40-mesh materials were small and of little significance. The 100-mesh calcium limestone, however, was definitely superior to the magnesium limestone of the same degree of fineness throughout the 4-week period, although the difference tended to become less from week to week.

The same general relationships were observed where the liming materials were applied at the other rates, except that the differences were not so pronounced in the soils limed at the rate of 1½ tons per acre, and they were a little greater in the soils limed at the rate of 6 tons per acre. The differences resulting from different amounts of liming materials were primarily of degree rather than kind.

The pH of the soil treated with the limestones, regardless of the quantity and fineness, was increased above that of the untreated soil, the increases being greater where the larger amounts of limestone were applied.

INFLUENCE OF CALCIUM AND MAGNESIUM LIMESTONES ON THE NITRATE CONTENT OF GRUNDY SILT LOAM

The nitrate content of the soil treated with various amounts of calcium and magnesium limestones and pure calcium and magnesium carbonates was determined at intervals of 1, 2, 3 and 4 weeks. The results are presented in table 9.

In general, little or no difference was noted in the effects of the calcium and magnesium materials on the nitrate content of the soil. An increase was obtained with an increase in time, the nitrate content being somewhat higher in most cases at the end of the experiment than after one week.

INFLUENCE OF CALCIUM AND MAGNESIUM LIMESTONES ON THE NITRIFYING POWER OF GRUNDY SILT LOAM

The effect on nitrification of various additions to this soil of calcium and magnesium limestones of different degrees of fineness and of the pure carbonates was determined at intervals of 1, 2, 3, and 4 weeks . The results are shown in table 10.

TABLE 9. THE NITRATE CONTENT OF GRUNDY SILT LOAM TREATED WITH CALCIUM AND MAGNESIUM LIMESTONES OF VARIOUS DEGREES OF FINENESS AND AMOUNTS. RESULTS EXPRESSED IN p.p.m.

Time in weeks	No lime	Calcium limestone and carbonate					Magnesium limestone and carbonate				
		10-mesh	20-mesh	40-mesh	100-mesh	Pure $CaCO_3$	10-mesh	20-mesh	40-mesh	100-mesh	Pure $MgCO_3$
1½ tons per acre											
1	30.62	35.88	32.40	33.68	40.52	41.57	36.24	34.97	32.99	38.98	41.30
2	50.56	59.16	56.35	56.64	49.54	56.25	60.27	58.40	55.36	45.01	61.66
3	82.48	84.77	83.44	73.14	77.50	83.56	85.68	79.31	75.12	78.84	78.84
4	84.30	61.78	79.14	80.42	81.56	80.98	92.20	92.51	95.95	80.57	89.59
3 tons per acre											
1	30.62	35.44	35.60	36.36	46.74	43.54	35.72	30.32	36.20	38.84	40.46
2	50.56	61.42	56.74	54.80	67.52	75.13	60.74	58.40	57.50	61.66	77.48
3	82.48	88.40	70.64	80.40	85.92	91.56	88.28	72.32	79.02	68.76	82.81
4	84.30	73.26	80.24	75.34	88.21	89.02	90.20	94.76	73.00	68.91	92.64
6 tons per acre											
1	30.62	35.64	35.17	39.61	46.20	33.68	35.96	34.24	38.65	41.40	32.89
2	56.56	57.86	60.16	59.58	81.45	85.35	59.48	56.44	63.88	71.46	73.40
3	82.48	89.39	73.06	77.30	103.91	103.56	88.52	71.12	70.96	88.06	74.44
4	84.30	75.70	81.32	82.14	108.30	116.96	93.02	96.98	85.29	89.60	107.00

TABLE 10. THE NITRIFYING POWER OF GRUNDY SILT LOAM TREATED WITH CALCIUM AND MAGNESIUM LIMESTONES OF DIFFERENT DEGREES OF FINENESS AND IN VARIOUS AMOUNTS. RESULTS EXPRESSED IN p.p.m.

Time in weeks	No lime	Calcium limestone and carbonate					Magnesium limestone and carbonate				
		10-mesh	20-mesh	40-mesh	100-mesh	Pure $CaCO_3$	10-mesh	20-mesh	40-mesh	100-mesh	Pure $MgCO_3$
1½ tons per acre											
1	36	36	37	37	41	40	36	36	38	40	46
2	96	102	109	109	139	145	91	91	96	139	119
3	139	142	161	166	234	239	135	138	148	174	193
4	188	211	222	228	255	228	209	207	254	274	280
3 tons per acre											
1	36	36	36	39	46	46	36	37	40	48	52
2	96	109	117	121	170	171	93	96	120	143	155
3	139	163	178	266	273	293	140	149	190	217	242
4	188	219	246	263	320	311	213	197	273	313	308
6 tons per acre											
1	36	36	38	40	37	36	36	38	42	51	31
2	96	108	123	160	178	169	96	104	136	174	151
3	139	174	189	329	329	317	134	163	200	276	271
4	188	260	291	333	340	359	221	250	372	388	353

The data indicate that the quantities of nitrate nitrogen produced from the oxidation of ammonium sulfate were considerably greater in the limed soils than in the unlimed soils, especially during the later periods of the experiment. The increase in the quantity of nitrates produced was influenced by quantity and degree of fineness of the limestone applied. Three weeks after the beginning of the experiment the untreated soil contained 139 p.p.m. of nitrate nitrogen. In the soil treated with 40-mesh calcium limestone at the rate of 3 tons per acre the nitrate content increased to 266 p.p.m., while with the 40-mesh magnesium limestone the amount of nitrate nitrogen present was 190 p.p.m.

The data obtained in the nitrification tests on the soils treated with 3 tons of the liming materials are shown graphically in fig. 2. It is apparent that none of the lime treatments had much influence on the extent of nitrification during the first week. By the second week, however, the nitrification had increased appreciably and there was some evidence of differences in the effects of the two limestones. The calcium limestone seemed to be slightly more effective than the magnesium limestone. These differences were even more pronounced by the third week but by the fourth week they had practically disappeared.

These results can be more readily understood if two facts are kept in mind: (1) That the principal effect of the limestone is in neutralizing the acidity produced in the nitrification process, (2) and also that in the hydrogen-ion concentration studies previously discussed it was found that the calcium limestone reacted with the soil acidity more rapidly than the magnesium limestone during the first few weeks after application while at the later periods the magnesium limestone was practically as effective. It appears that the reactivity of the limestones with the acidity of the soil and with the acids produced in the nitrification process is the principal factor in controlling the extent of nitrification. Hence, the conclusions concerning the effects of these limestones on the nitrifying power of a soil should be very similar to those obtained from studies on the hydrogen-ion concentration of the soil. In table 11 are presented the results of pH determinations on the soils in which nitrification had been in process. These data indicate that insofar as the hydrogen-ion concentration is concerned there are two opposing forces at work. The first is the limestone reacting with the acid with a tendency toward an increase in pH and the second is the production of more acid from the ammonium sulfate by microorganisms with a tendency toward a decrease in the pH. There was a considerable decrease in the pH

TABLE 11. THE pH OF GRUNDY SILT LOAM TREATED WITH LIMESTONE OF DIFFERENT DEGREES OF FINENESS AND IN VARIOUS AMOUNTS PER ACRE AND ALSO WITH AMMONIUM SULFATE FOR NITRIFICATION TESTS.

Time in weeks	No lime	Calcium limestone and carbonate					Magnesium limestone and carbonate				
		10-mesh	20-mesh	40-mesh	100-mesh	Pure $CaCO_3$	10-mesh	20-mesh	40-mesh	100-mesh	Pure $MgCO_3$
1½ tons per acre											
1	5.15	5.19	5.27	5.49	6.04	5.98	5.22	5.22	5.33	5.60	5.97
2	5.25	5.27	5.34	5.57	5.83	5.79	5.18	5.14	5.22	5.54	5.75
3	4.74	4.91	4.93	5.06	5.18	5.23	4.75	4.86	4.96	5.16	5.25
4	4.80	4.66	4.70	4.80	4.95	5.06	4.69	4.71	4.77	4.86	4.90
3 tons per acre											
1	5.15	5.28	5.27	5.49	6.04	5.98	5.18	5.26	5.48	6.15	6.71
2	5.25	5.31	5.55	5.95	6.20	6.35	5.18	5.18	5.53	6.17	6.43
3	4.74	5.00	5.13	5,34	5.41	5.62	4.75	4.93	5.10	5.54	5.61
4	4.80	4.69	4.83	5.03	5.15	5.15	4.69	4.97	4.92	5.07	5.51
6 tons per acre											
1	5.15	5.45	5.75	6.30	6.62	7.67	5.29	5.36	5.79	6.70	7.70
2	5.25	5.59	5.93	6.62	7.23	7.31	5.16	5.37	5.92	6.64	7.43
3	4.74	5.43	5.41	5.82	6.61	6.92	4.77	5.16	5.45	6.15	7.01
4	4.80	5.16	5.02	5.58	8.59	6.37	4.73	4.95	5.24	5.93	6.67

of the unlimed soils as nitrification proceeded. There was also a decrease in the pH of the limed soils as a result of the acids produced by the microorganisms. The reduction in pH in this case, however, was not nearly so great as it was in the un-

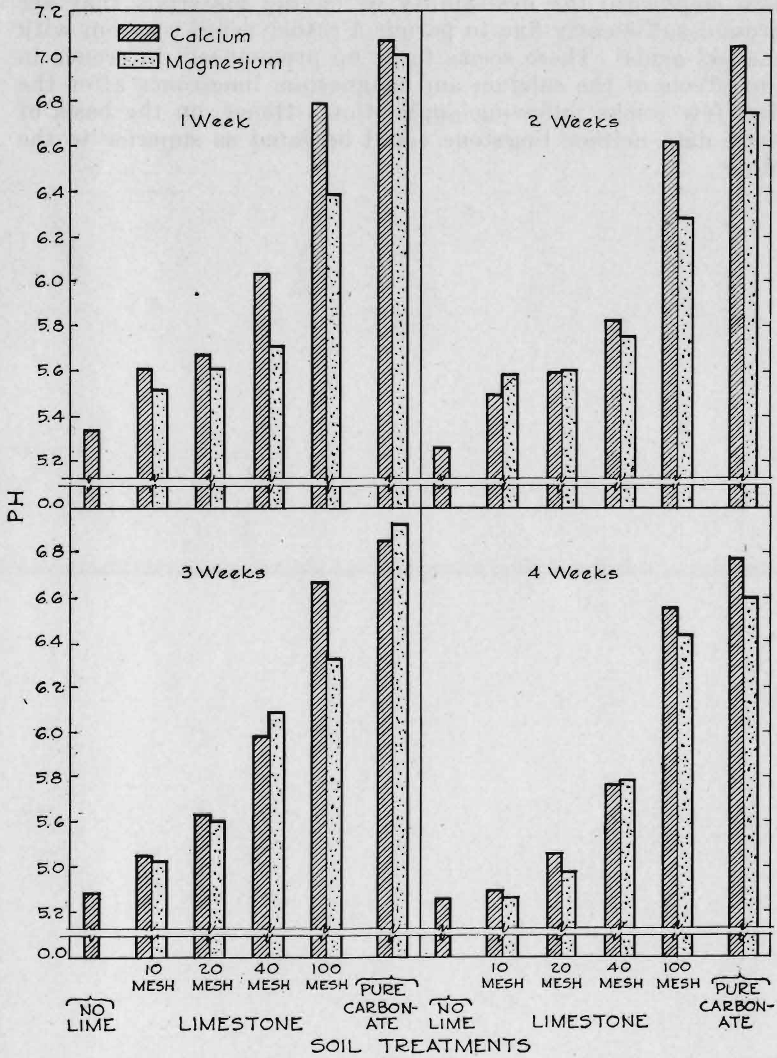

Fig. 2. The nitrifying power of Grundy silt loam treated with calcium and magnesium limestones of different degrees of fineness and with the pure carbonates at the rate of 3 tons per acre.

treated soil in spite of the fact that more nitrification occurred in the limed soils as is indicated by the data of table 10. These results emphasize the necessity of having sufficient lime in soils, first to neutralize the acids already present, and second to neutralize the acids produced in biological activity. They also emphasize the desirability of having materials that are ground sufficiently fine to permit a rather rapid reaction with the soil acids. There seems to be no pronounced difference in the effects of the calcium and magnesium limestones after the first few weeks following application. Hence, on the basis of these data neither limestone could be rated as superior to the other.